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Page 16, Table 6 - Last row, column 4, symptom rate, should be 16 not 20.

Page 19, Table 8 - Row 6, column 3, E should be W.

Row 7, column 3, W should be E.

Row 8, column 3, E should be W.

Row 9, column 3, W should be E.

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Health Effects Criteria for Fresh Recreational Waters

by

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FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The complexities of environmental problems originate in the deep interdependent relationships between the various physical and biological segments of man's natural and social world. Solutions to these environmental problems require an intergrated program of research and development using input from a number of disciplines. The Health Effects Research Laboratory, Research Triangle Park, NC and Cincinnati, OH conducts a coordinated environmental health research program in toxicology, epidemiology and clinical studies using human volunteer subjects. Wide ranges of pollutants known or suspected to cause health problems are studied. The research focuses on air pollutants, water pollutants, toxic substances, hazardous wastes, pesticides and nonionizing radiation. The laboratory participates in the development and revision of air and water quality criteria and health assessment documents on pollutants for which regulatory actions are being considered. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of environmental regulatory decisions involving the protection of the health and welfare of all U.S. inhabitants.

This report provides an assessment of the relationship between microbiological indicators of water quality and illness that may have resulted from swimming. The data base resulted from a series of in-house and extramural epidemiological-microbiological research projects designed to develop the criterion for fresh waters. The development and periodic reevaluation of such criteria is mandated by Section 304(a)1 of Public Law 92-500: Federal Water Pollution Control Act Amendments of 1972; Clean Water Act of 1977.

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Health Effects Research Laboratory

ABSTRACT

A criterion for the quality of the bathing water, based upon swimming-associated gastrointestinal illness, was developed from data obtained during a multi-year freshwater epidemiological-microbiological research program conducted at bathing beaches near Erie, Pennsylvania and Tulsa, Oklahoma. Three bacterial indicators of fecal pollution were used to measure the water quality, *E. coli*, enterococci and fecal coliforms. A good correlation was observed between swimming-associated gastrointestinal symptoms and either *E. coli* or enterococci densities in the water. Fecal coliform densities showed little or no correlation to gastrointestinal illness rates in swimmers. In general, high gastrointestinal illness rates were associated with high densities of fecal indicator bacteria. A comparison of the freshwater results with the results obtained from studies at marine bathing beaches indicated that a separate criterion should be used with each type of bathing water.

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SECTION 1

INTRODUCTION

The current EPA recommended criteria for bathing waters is that given in Quality Criteria for Water (1) which states:

> "Based on a minimum of five samples taken over a 30-day period, the fecal coliform bacterial level should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 per 100 ml."

This criterion, which is used by 95% of the states and territories of the United States (2), was first proposed by the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration in 1968 (3). The NTAC used epidemiological data collected by the United States Public Health Service (USPHS) from 1948-1950 (4) to develop the criteria for recreational bathing waters. The criterion was closely examined in 1972 by a committee of the National Academy of Sciences—National Academy of Engineers (NAS-NAE) and they concluded that the epidemiological data base used to develop the NTAC criterion was too limited to be scientifically defendable (5). The NAS-NAE committee decided not to recommend a criterion for recreational bathing waters based on the paucity of epidemiological information available.

In 1972, the Environmental Protection Agency (EPA) initiated a long-term recreational water quality research program that was to examine the relationship between water quality and swimming-associated acute infectious disease. The first phase of the program, from 1972 to 1978, was conducted at multiple marine bathing beaches in New York, Louisiana and Massachusetts. The result of these studies was a marine recreational water criterion which described a direct linear relationship between swimming-associated gastroenteritis and water quality which was indexed by the density of enterococci in the water (6).

From 1978 to 1982, the EPA recreational water quality research program was directed at freshwater bathing areas. This report will describe and summarize the results of freshwater beach studies conducted in Pennsylvania and Oklahoma, and will present two fresh recreational water criteria, which relate swimming-associated gastroenteritis to water quality, characterized with either one of two bacterial indicators, enterococci or *E. coli*. It will be shown that the model developed for the marine criterion, i.e., a direct linear relationship, has been validated by the freshwater studies and, lastly, the results of the marine studies will be compared to those of the freshwater results to show that a single criterion cannot be used for marine and fresh bathing waters.

The material presented in this report is a natural extension of the information given in "Health Effects Water Quality Criteria for Marine Recreational Waters" (6). Many references will be made to that report, since the rationale for the marine studies and the study design have been used in the freshwater studies. Whenever possible the data presentations in this report will be in such a manner that the results can be compared directly to those of the marine studies. Although most of the information pertinent to developing a water quality criterion are included in the organization of this report, there are certain elements that have been omitted, which can be found in the marine water quality report, such as the two sections which relate to water quality indicators and the limitations associated with the use of criteria developed with bacterial water quality indicators of enteric origin.

SECTION 2

CONCLUSIONS

The results of the freshwater bathing beach studies conducted at two sites over a three-year period lead to the following conclusions.

1. Swimming-associated gastrointestinal illness is related to the quality of the bathing water. A direct linear relationship was observed between highly credible gastrointestinal illness and bacterial densities of two indicators of fecal contamination, enterococci and *E. coli*.
2. The relationship between the rate of swimming-associated illness and bacterial indicator density was almost identical for two of the indicators examined, *E. coli* and enterococci. Thus, either indicator can be used to measure the potential for swimming-associated illness in bathing waters. Fecal coliforms showed no relationship to the rate of swimming-associated gastrointestinal illness.
3. The criterion developed for marine bathing waters is not applicable to fresh bathing water. At equivalent indicator densities, the swimming-associated illness rate was approximately three times greater in seawater swimmers relative to that in freshwater swimmers.

SECTION 3

BACKGROUND

Swimming-Associated Outbreaks of Disease

The history of disease outbreaks and illness associated with poor quality bathing water has been described in many reviews on this subject (7,8,9). A listing of the most frequently referenced literature on swimming-associated illness is given in Table 1. This table is instructive in the sense that it shows that some factors assumed to be important in past considerations of the hazards related to swimming in polluted water may have little relevance today. For instance, it is obvious that reports of disease in swimmers caused by *Salmonella* species began to decline in the 1940's and none were reported after the Australian outbreak which occurred in 1958. Two factors probably contributed to the decrease in *Salmonella* related illness in swimmers. First, there was the steady increase in the number of sewage treatment plants practicing disinfection, especially in large population centers, and second, there was a widespread use of newly discovered antibiotics which greatly aided in limiting the spread of disease and, thereby, the number of ill individuals in the discharging population. Another obvious point is the lack of swimming-associated outbreaks caused by poliovirus. Although strong evidence relating this virus to disease contracted by swimming has never been presented, many of the early studies

Table 1. Outbreaks of Disease Associated with Swimming in Natural Waters

Year	Location	Etiologic Agent	Water Quality	No. Cases No. at Risk	Reference
1909	Walmer, England	*Salmonella*	U*	34/NG	7
1921	Connecticut	*Salmonella*	U*	6/NG	17
1932	New York	*Salmonella*	U*	51/NG	16
1942	California	*Salmonella*	U*	NG/NG	30
1947	Beccles, England	*Salmonella*	U*	9/NG	58
1958	Perth, Australia	*Salmonella*	U*	15/NG	10
1973	Vermont	Coxsackie B	U	21/33	11
1974	Niort, France	Coxsackie A_{16}	*E. coli* 50-1000/ 100 ml	5/NG	18
1974	S. Carolina	Hepatitis-A	U*	14/30	15
1976	Iowa	*Shigella*	U	31/45	12
1982	Michigan	Norwalk Agent	U	126/NG	14

U - Water quality not measured.
* - Suspected to be grossly polluted.
NG - Not given.

on the effect of polluted water on swimmers were probably stimulated by the anxiety created by the then incurable disease caused by poliovirus.

After the 1958 outbreak of salmonellosis in Australia (10) there was a long period when no outbreaks of swimming-associated illness were reported in the literature. This lull was broken in 1973 when Hawley *et al.*, (11) reported an outbreak of illness, apparently swimming related, caused by Coxsackie B virus. Most of the reports from 1973 to the present have dealt mainly with viral mediated swimming-related disease. The exception to the viral etiology of swimming-associated illness was the outbreak attributed to *Shigella sonnei* which occurred downstream from Dubuque, Iowa on the Mississippi River in 1976 (12). This pathogen differs from most of the bacterial species associated with illness in swimmers in that it has a low infective dose. As few as ten ingested *Shigella* have caused illness in a significant percentage of volunteers (13).

A notable characteristic of the early outbreaks and those which have occurred more recently is the lack of good data describing the quality of the water. It is almost characteristic of outbreaks that they do not occur coincidental to measuring the quality of the water. This was true in the Michigan (14), Dubuque, Iowa (12), South Carolina (15) and Perth, Australia (10) outbreaks. In all of these incidents the water quality was usually examined before or subsequent to, but not during the outbreaks.

The Michigan outbreak, for instance, occurred one week after the water had been analyzed and one week before the next planned sampling of the water (14). In the Dubuque outbreak the water quality was not examined until one week after the illnesses were first observed (12). Bryan noted that coliforms were present in the South Carolina lake water where the Hepatitis A outbreak occurred, but densities were not reported (15). The Australian outbreak was similar to other outbreaks in that it was only after the onset of cases of illness that the water quality was examined and high concentrations of fecal coliforms were observed.

Investigators in both the Vermont and Beccles, England outbreaks did not examine the water for water quality indicators. They did, however, isolate the etiologic agent from water samples obtained from swimming waters where patients had been bathing.

Three outbreaks apparently were associated with swimming in grossly polluted water. The Walmer, England outbreak report clearly implicated sewage from a nearby outfall as the source of the typhoid fever among army recruits (7). The often cited somewhat obscure reports linking typhoid fever with bathing in polluted harbor water in New York (16) and New Haven (17), on the other hand, did not clearly establish the association between swimming activity and disease. The New York report indicated an unusual increase in the number of reported cases of typhoid in the summer of 1932. The cases were sporadic and did not constitute an outbreak. Neither water nor milk was implicated as a common source of the etiologic agent. The report stated that, "From all the data at hand it is very probable that most of the increase (in typhoid fever) may be charged to bathing in polluted harbor waters condemned by the Department of Health." The report also states that, "It should be noted that in Brooklyn, up to the age of twenty, the infections among males are nearly double the number among females, a fact which lends support for the belief that bathing in polluted waters has played an important part in the increased prevalence of typhoid fever." The 1921 report by Ciampolini (17) on the incidence of typhoid in New Haven was more detailed, but similar to the New York report in that an excess of cases was noted in an area of the city near the harbor. A total of 32 cases was reported from January to December and none of these could be attributed to drinking water or food. Many of the cases were due to person-to-person contact. Only nine of the cases were thought to be due to bathing. The nine cases lived in close proximity to the harbor, and all had a common history of bathing at some time or other in the harbor which had been shown some years before to be grossly polluted with sewage. Thus, in both the New York and New Haven typhoid outbreaks, swimming activity was

perceived as being marginally associated with an excess of cases but not the sole cause of the outbreak attributable to a single source, such as polluted harbor water.

In contrast to the outbreaks discussed above, the Coxsackie A_{16} outbreak reported by Denis *et al.* (18) was quite thorough with respect to its description of the quality of the water at the time of the incident. Not only was the etiological agent isolated from the lake water but *E. coli,* group D streptococci and *Pseudomonas aeruginosa* also were detected and enumerated.

The nature of disease outbreaks is such that the relationship between an illness and a common source of an etiological agent is clearly defined because of some coherent characteristic of the affected group such as a common affiliation or activity. Thus, disease outbreaks are instructive in the sense that they establish relationships such as that between swimming-associated illness and water quality which probably would not have been discovered had the members of the group not had some type of common characteristic. Most of the above outbreaks fit this description in that the affected individuals belonged to a group, such as army recruits or boy scouts, or they were taking part in a common activity such as camping or picnicking. The occurrence of disease in these groups was instrumental in showing that recreational activity in poor quality water was a reasonable means by which pathogens could be disseminated from point sources of pollution to susceptible individuals. However, disease outbreaks are not very useful for establishing the relationship between the incidence of disease and some measure of water quality because the water quality is seldom measured at the time of the outbreak. Thus, the study of outbreaks serves a valuable purpose, but in order to establish water quality criteria or guidelines for recreational waters, a more purposeful, directed means of obtaining health effects information must be used. Epidemiological studies provide a rational means for obtaining the desired information.

Retrospective Epidemiological Studies

Only three studies have been published which attempted to assess the health risks of swimming by identifying cases of a specific illness and then determining if that illness was somehow related to swimming activity. The first such study was reported by the Public Health Laboratory Service (19) in 1959. They described an intensive effort over a five-year period to identify patients with enteric fever whose illness might be associated with a history of swimming. Attempts were made to see if the frequency of enteric illness in coastal areas differed significantly from those in the national population. The assessment of whether or not a case of paratyphoid or typhoid fever was related to swimming was made on the basis of (1) the organism causing the disease being the same type as that found in the bathing water, (2) other common sources of infection being excluded, (3) the accidental swallowing of a good deal of water, (4) the bathing waters being highly polluted and (5) a bathing episode prior to the onset of the illness that was consistent with the time interval of the incubation period. Using these criteria, no evidence could be found that seaside residents had a higher rate of enteric disease than the nation as a whole. In all, between 1954 and 1959, only 10 cases of enteric fever were found whose histories suggested a swimming-associated infection and of these ten cases only four satisfactorily fit the criteria. These four cases were associated with beaches known to be grossly contaminated with untreated sewage. It is interesting to note that the minimal findings of this study frequently have been interpreted to mean that swimming in contaminated water does not pose a health risk until the quality of the water is judged to be unsatisfactory based on aesthetic grounds.

The second retrospective study on the risks associated with swimming also was reported by Moore (20). In this study, the case-control method was used to determine if the swimming experiences of children with diagnosed poliomyelitis differed from those of children the same sex and age who did not have the disease. This was accomplished by carefully recording the swimming experiences for the three weeks

prior to the onset of illness for each patient and for each control individual at the time they were selected. One hundred and fifty matched pairs were selected during a two-year period. The results of the study indicated that the frequency of swimming during the three weeks preceding the onset of symptoms, in the index case, was no greater in patients than it was in controls. The conclusion reached was that a history of swimming is not related to contracting poliomyelitis. This study and the previous one seriously challenged the premise that swimming in contaminated waters posed a significant health problem.

A third study of this type was conducted by D'Alessio *et al.* in the Madison, Wisconsin area in 1977 (21). They examined the swimming histories of 679 well children and 216 ill children. Enteroviruses were isolated from 119 of the ill children. Statistical analysis of these data indicated that the risk of enteroviral disease was 3.4 times greater in children who swam exclusively at beaches than in nonswimmers. The risk was 10.6 times greater in children who swam exclusively at beaches if they were less than four years old. These positive findings should be accepted with some skepticism because, as the authors point out, swimming was not rigidly defined and, therefore, person-to-person contact cannot be entirely ruled out as a means of transmission.

In general, when little is known about etiologic factors, retrospective studies are useful for discovering underlying factors associated with specific disease. This usefulness does not extend much beyond identifying associations between specific etiologic agents and exposure factors, which is similar to what is accomplished by examining outbreaks of disease. Furthermore, this type of study gives no information about the incidence rates in exposed and non-exposed individuals, both of which are critical elements for determining the importance of certain exposure factors. Retrospective studies have been used in spite of these recognized limitations, mainly because they are much less expensive than studies where an exposed group is identified along with a demographically similar control group and both are followed for a period of time to assess the proportions of a response in each group, i.e., prospective studies.

Prospective Epidemiological Studies

The first attempts to show a relationship between swimming-associated health effects and water quality using a prospective epidemiological study design were carried out in the late 1940's and early 1950's by the USPHS (4). The studies were conducted at two freshwater sites, one on Lake Michigan at Chicago, Illinois and another on the Ohio River at Dayton, Kentucky, and at two marine sites on Long Island Sound at New Rochelle and Mamaraneck, New York. Essentially the same experimental design was used in each of the three studies. At each location, an attempt was made to select two beach sites, one with a high coliform density and one with a low coliform density. At the New York and Chicago locations beaches were available that had fairly homogeneous populations nearby and which fit the water quality requirements of the study design. At the Ohio River location two beaches were not available and, therefore, the population which frequented the public swimming pool was used as the study group swimming in water with low coliform densities. Swimming activity and the occurrence of gastrointestinal, respiratory or "other" symptoms were recorded on a "calendar" given to each participant at the beginning of the study. The "calendars" were collected when the study ended. Statistically significant illness rates were determined by comparing the observed rates in swimmers to an age-adjusted expected rate calculated using the rates observed in the total study population. The coliform densities at the study sites were monitored daily. Swimming-associated gastroenteritis was not observed at the marine sites or at the Lake Michigan site. However, the Ohio River study showed that gastrointestinal illness was observed more frequently than expected in river swimmers, based on the illness experience of all members of the study population, when the median coliform

density was about 2300 per 100 ml. This study established the first experimental link between gastrointestinal illness in swimmers and bathing water contaminated with fecal material. The design of the USPHS studies has been criticized on a number of issues (22,23). The most frequent criticisms address the poor definition of swimming activity and the fact that swimming days were not related directly to water quality measurements. The use of the "calendar" system was also faulted because it allowed for possible memory lapses between the swimming episode and the collection of data.

In 1972 the United States Environmental Protection Agency (EPA) began a series of epidemiological-microbiological studies at marine bathing beaches that were designed to eliminate some of the deficiencies of the earlier USPHS studies. The objectives of the EPA study were to determine if there was a health risk associated with swimming in polluted marine waters and what measure of water quality best relates to swimming-associated illness, and to develop a criterion for swimming-associated health effects and some measure of water quality if such a relationship existed. The EPA epidemiological-microbiological studies were conducted in New York City, New York, Lake Pontchartrain, Louisiana and Boston, Massachusetts (6). The results of the marine water studies indicated an excess of gastrointestinal illness occurred in swimmers relative to a nonswimming control group in water contaminated with fecal material and that the swimming-associated gastroenteritis was linearly related to the water quality, as measured with a bacterial indicator. Several indicators of fecal pollution were examined to determine which one best described the relationship between the quality of the water and the swimming-associated health effect. Enterococci were shown to have the strongest relationship to swimming-associated gastroenteritis. Fecal coliforms, the currently recommended bacterial indicator of water quality, showed no correlation to the incidence of swimming-associated gastroenteritis. The final report of the marine recreational water quality study concluded that water quality standards or guidelines for marine bathing beaches be based on a criterion which describes a direct linear relationship between bathing water quality, measured with enterococci, and the incidence of swimming-associated gastroenteritis. The utility of the criterion was that it could be used at any level of government to set standards or guidelines. The local regulatory body could determine an acceptable level of risk, based on community perceptions, desires and needs, and translate that risk level to a water quality standard or guideline indexed by the enterococcus group. The marine studies had, in fact, established a valid epidemiological criterion or model which had been unavailable to groups of standard setters in the previous sixty years.

Water Quality Standards for Bathing Beaches 1924-1980

The evolution of national guidelines and standards for bathing places in the United States began with the formation of the American Public Health Association Committee on Bathing Places (24). One of the committee's first actions was to survey physicians and public health officials across the United States to determine if bathing places might be considered as important for the transmission of infections. A majority of the replies expressed the opinion that disease and even epidemics could be attributed to bathing beach activity. The committee report for 1924, tentatively adopted a *Bacterium coli* standard for swimming pools, but did not extend the standard to natural bathing waters (25). In 1933, the committee considered natural bathing waters in great detail but did not adopt a bacterial standard because they did not want to propose arbitrary standards or measures that might promote public hysteria about the dangers of outdoor bathing places (26). The reluctance to propose bacterial standards for outdoor bathing places was again evident in the 1936 and 1940 reports of the committee wherein classification schemes were discussed but actions were not taken despite pressures to do so from various quarters (27,28). The basis for this general reluctance of the committee to propose standards for outdoor bathing places was the paucity of epidemiological evidence linking illness to bathing in

polluted water. The 1936 report noted "the committee is unconvinced that bathing places are a major public health problem," and the 1940 report reiterated this position by stating, "Epidemiological evidence does not appear to warrant the conclusions that bathing places constitute a major public health problem."

The committee did consider the means of classifying natural bathing waters. The 1933 report of the committee noted that California had proposed a standard of 10 *B. coli* per c.c. and that New York City had a standard of 30 *B. coli* per c.c. (26). The State of Connecticut also had proposed a system of classification based on *B. coli* densities per 100 ml. Waters were classified A, B, C and D. Class A, 50 *B. coli* per 100 ml or less, was considered very good and Class D, more than 1000 *B. coli* per 100 ml, was very poor. The 1936 report stated it was reasonable to conclude that water having a *B. coli* density less than 1000 per 100 ml is probably acceptable (27). As late as 1951 this observation of the APHA Committee on Bathing Places appeared to be still reasonable (28). Streeter (29) summarized the bathing and recreational standards of 11 states and regions. In 9 of the 11 standards, the limiting coliform density was 1000 per 100 ml, either as an average or a maximum. Discher (8) listed the current standards for all of the states in 1963 and 70% of them considered waters containing less than 1000 coliforms per 100 ml acceptable.

The 1000 coliform per 100 ml standard first used by many of the States was not derived from a single line of evidence. Regulatory groups and some states independently established their standards based on available state-of-the-art information. The California standard, for instance, was arbitrarily set by the California Bureau of Sanitary Engineering over forty years ago (30). The standard was not based on epidemiological evidence, but rather on the perception that it related well with the drinking water standard of that time, that there was no epidemiological evidence of health effects within the standard, that the 10 coliforms per ml level could easily be attained and, lastly, that any less stringent standard might result in waters that would be aesthetically unacceptable. Connecticut, on the other hand, did not want to set up a classification scheme that would be too arbitrary and, thus, they used a relative scheme (31). They used coliform bacteria to index four classes of water. Class A, B, C and D ranged from 0-50, 51-500, 501-1000 and over 1000, respectively. An extensive survey of the Connecticut shoreline indicated that 92.8% of the samples contained less than 1000 coliforms per 100 ml (32,33,34). This classification agreed well with a sanitary survey classification which showed that only 6.9% of the shoreline was designated as poor. The high correlation led to the acceptance of waters having less than 1000 coliforms per 100 ml. Thus, the standard in this case was based more on easy attainment in over 90% of the shoreline rather than epidemiological data. Streeter (29) adopted a more analytical approach in arriving at the 1000 coliform per 100 ml criteria. He used the coliform-*Salmonella* ratio developed by Kehr and Butterfield (35), the number of bathers exposed, the approximate volume of water ingested daily per bather and the average coliform density per ml of bathing water to develop a bather risk factor. Streeter speculated that in water containing 1000 coliforms per 100 ml there would be no great hazard for individual bathers, at least from *Salmonella typhosa*. It is interesting to note that in spite of the use of different means for obtaining a standard measure for water quality, either arbitrarily, practically, or analytically, the final results were approximately the same.

The coliform index was the bacteriologic standard of choice until 1968 when the NTAC to the Federal Water Pollution Control Administration recommended that fecal coliforms, a subgroup of the coliform group (now designated total coliforms), be used as the bacterial indicator of water quality (3). The recommendations of the NTAC committee were based on prospective epidemiological studies conducted by the USPHS in 1948, 1949 and 1950 (4). These studies had indicated that gastrointestinal illness in swimmers was significantly higher than in a control population when coliform densities averaged 2400 per 100 ml (median) on the Ohio River and that multiple symptomatic illness (respiratory, gastrointestinal and

"other") was significantly higher in swimmers than in nonswimmers when the geometric mean coliform density was 2300 per 100 ml at a Chicago beach. The NTAC committee used fecal coliform and total coliform density data collected on the Ohio River in the mid-1960's to determine that the fecal coliform subgroup was approximately 18% of the total coliform group. The committee reasoned that if a detectable health effect was observed at a coliform density of 2300-2400/100 ml then the recommended water quality standard should include a factor of safety. Eighteen percent of one-half of the coliform density at which a detectable effect occurred was arbitrarily chosen as the appropriate level and, therefore, 200 fecal coliforms per 100 ml became the recommended standard.

The recommended fecal coliform standard has been adopted by many states and municipalities in spite of the fact that the 1972 NAS-NAE report on Water Quality Criteria did not recommend guidelines for recreational water because of a paucity of valid epidemiological data (5). The NAS-NAE committee was not alone in questioning the validity of the USPHS studies which had been summarized by Stevenson in 1953 (4). Henderson (9) and Moore (23) have discussed the inadequacy of the epidemiological studies used to support the NTAC recommendation.

In 1972, the EPA recommended a recreational water quality standard similar to that proposed by the NTAC (1). Although the Stevenson report (4) is referenced in the rationale for the criterion, the relationship between the USPHS studies and the 200 fecal coliform per 100 ml standard was not described. Rather, the relationship between the frequency of occurrence of *Salmonella* and density of fecal coliforms was emphasized. The rationale indicated that the frequency of occurrence of *Salmonella* falls between 60 and 100% when the fecal coliform density was greater than 200 per 100 ml. This recommended criterion is the one most widely used in the United States today.

SECTION 4

FRESHWATER STUDIES

The establishment of a sound relationship between swimming-associated illness and marine water quality still left unanswered the question of whether or not this criterion could be used in fresh water environments. The USPHS studies on the Ohio River indicated that there was an excess of gastrointestinal illnesses among swimmers when compared to control populations, which could properly be characterized as barely detectable (4). Furthermore, the USPHS studies could not find a swimming-associated gastrointestinal illness effect at Chicago beaches or at marine beaches on Long Island Sound. Since the EPA studies did show an effect at marine bathing beaches, the expectation was that, not only would a swimming-associated effect be found, but that the freshwater swimming-associated illness rates might be significantly higher than the marine rates.

This report examines the data collected during studies carried out by the University of Oklahoma, Oklahoma City, Oklahoma and Gannon University, Erie, Pennsylvania under the auspices of the EPA. The objectives of this report were to: (1) determine if the swimming-associated health effect/water quality criterion model established in the marine studies could be confirmed at freshwater bathing beaches, (2) determine which indicator of water quality shows the strongest relationship to swimming-associated health effects, if such a relationship exists and (3) determine if the marine water quality criterion is applicable to freshwater bathing areas.

Experimental Design

The design of the freshwater studies followed, whenever possible, the plan used in all of the marine studies (6). The highlights will be reviewed here for the convenience of the reader. The beach surveys or trials were conducted only on weekends to take advantage of the large populations using the bathing beaches and to permit more intensive monitoring of water quality during the time of swimming activity.

Swimming activity was rigidly defined as having all upper body orifices exposed to the water. Interviewers were instructed to observe the individuals they were interviewing for signs of complete body immersion, such as wet hair. This was not always possible and reliance was then placed in the responses to questions about swimming activity. The nonswimming control group was selected from beachgoers who did not meet the definition of a swimmer.

The beach interviews were conducted in two phases. In the first phase, trained interviewers approached beachgoers who were about to leave the beach area and solicited their cooperation in the study. Whenever possible, family units were sought because information on multiple individuals could be obtained from one person, usually an adult member of a family. During this initial contact, the following information was obtained on each participant: sex, age, race and ethnicity, if the person swam and got their head and face wet, length of time and time of day in the water, the illness symptoms they may have had in the previous week, and for those who did not swim, the reason for not going into the water. An address and telephone number was requested so that follow-up information could be obtained. If an individual had gone swimming in the previous five days, they were not asked to participate in the study. Telephone interviews were conducted 8 to 10 days after the swimming experience. The eligibility of each participant was confirmed, i.e., they had not swam in the week following the initial contact, before they were queried about the

onset of any symptoms of illness that might have occurred during the time interval between the swimming experience and the follow-up telephone call.

The sites for the freshwater bathing beach studies were located at Keystone Lake, which is about 15 miles from Tulsa, Oklahoma, and on Lake Erie at Erie, Pennsylvania. Two sites were used on Keystone Lake, one set of beaches was less than three miles from the point of discharge of a sewage treatment facility (Beach W), and the other was located about five miles from the outfall (Beach E). In 1979 the sewage treatment system was two "full retention" lagoons, which discharged an average of 120,000 gallons per day of unchlorinated sewage. The following year the practice of releasing non-disinfected sewage into the lake was discontinued. After April of 1980, approximately 60,000 gallons per day of sewage was passed through one of the lagoons, then through an aeration basin after which it was adequately treated with chlorine before being discharged. Two sites also were used in the Lake Erie studies. Both sites were located at a State Park which is situated on a peninsula just north of the City of Erie. One beach is approximately three-quarters of a mile northwest of the outfall which discharges the treated sewage of a large urban population (Beach B). An activated sludge process is used to treat an average of 45 million gallons per day of sewage. The secondary treatment effluent was chlorinated before being discharged into the lake. The second beach is located on the opposite side of the peninsula from the effluent outfall (Beach A). This site does not receive pollutants from a point source and the quality of the water is usually good.

The key bacterial indicators of water quality which showed the strongest relationship to swimming-associated illness in the marine bathing beach studies were *E. coli* and enterococci. These two indicators were monitored in all phases of the freshwater studies. Fecal coliforms, the currently accepted bacterial indicator of water quality, were monitored in both years of the Keystone Lake Study and in two years of the Lake Erie Study. The enterococci, an indicator group which includes two species, *Streptococcus faecalis* and *Streptococcus faecium*, were enumerated with the method of Levin *et al.* (36). *E. coli* was enumerated by the method of Dufour *et al.* (37) and fecal coliforms were quantified according to the procedures outlined in Standard Methods for the Examination of Water and Wastewater (38).

The data from the freshwater bathing beach studies were analyzed with respect to the objectives of the recreational water quality research program. One of the goals of the program was to determine whether swimming in freshwater contaminated with sewage effluents results in a higher rate of gastrointestinal illness in swimmers relative to the rate observed in a beach-going, nonswimming reference group. This latter group had a tendency to be quite small at one of the study sites. The small number of nonswimmers is a phenomenon of freshwater beaches. Unlike marine beaches, where wading and sunning are more popular than swimming, the beach goers at freshwater beaches have a tendency to go into the water for extended periods and to immerse their bodies totally in the water. This greater water activity results in a much smaller nonswimming population from which a control group can be chosen. In order to overcome this limitation of the freshwater studies, it was necessary to pool the nonswimming control groups from each beach within a single swimming season to form a single control population. The homogeneity of the nonswimming control groups at the beaches of each study location with regard to age, sex, race, and socioeconomic status lent itself to this adjustment. The pooling of nonswimming control groups for each year increased the probability of detecting a difference in the incidence of illness between swimmers and nonswimmers if it does exist. The variables used to examine this relationship were the differences in symptomatic illness rates between swimmers and nonswimmers, and the density of bacterial indicators in the water at the time of swimming activity. Age was shown to be a confounding risk factor in the marine bathing beach studies (6) and, therefore, this factor was controlled in the analysis of the data. The Mantel-Haensel Chi Square test was used to determine if something other than random processes might account for

the observed differences in illness rates between swimmers and nonswimmers, i.e., exposure to contaminated bathing water (39).

A second goal was to determine if there is a direct relationship between swimming-associated gastrointestinal illness and water quality as observed in the marine bathing beach studies. Regression analysis was used to determine if a direct relationship exists between these variables (40).

Another goal of the study was to determine which bacterial indicator of water quality showed the strongest relationship to swimming-associated illness. Correlation analysis was used to measure the degree of association between gastroenteritis and the various indicators examined. Three statistics, the correlation coefficient, the regression coefficient and the standard error of the estimate, were used to characterize the strength of the association.

Finally, the relationship between health effects and water quality observed at freshwater bathing beaches was compared to the results obtained at marine bathing beaches. This latter comparison was used to determine if the criterion developed for marine bathing beaches is applicable to freshwater environments.

Lake Erie Study

The Lake Erie studies were conducted in 1979, 1980 and 1982 at beaches in a State Park near Erie, Pennsylvania. In 1979 and 1980 two beaches were used, one with good water quality and the other of excellent water quality, while in 1982 only the good quality beach was used. Both beaches met local and state standards for recreational waters.

The demographic characteristics of the study participants have been given elsewhere (41). In general, the sex ratio among swimmers was about 1:1 and among nonswimmers there was approximately twice as many females as males. These ratios were rather constant over the three-year study period. The age distribution at the beaches also was rather constant during the course of the studies. Among swimmers, the age group between 1 and 19 years old made up between 43 and 55% of the population, whereas in the nonswimmers that age group comprised approximately 23% of the population. The racial distribution of swimmers and nonswimmers, and the socioeconomic status of these two groups, as measured by a crowding index, was remarkably similar.

The high success rate for follow-up contacts was the result of repeated telephone calls until the participant was reached (Table 2). The average overall success rate was 92% during the three-year course of the study.

Table 2. Follow-up Success Rate for Beach Contacts at Lake Erie, Pennsylvania, 1979, 1980, and 1982

	1979		1980		1982
	Beach A	Beach B	Beach A	Beach B	Beach B
Total Contacts	2877*	2196	3126	2517	8493
Follow-up interviews completed	2650	1858	3087	2493	8211
No response	227	338	39	24	282
Success rate (%)	92	85	99	99	97
Total number of swimmers	3020	2056	2907	2427	4374
Total number of nonswimmers	1310	1039	1436	1558	1650

*Indicates number of group contacts.

A detailed analysis of the individual symptom rates is presented elsewhere (41). The rate of symptoms grouped by category is given in Table 3. Gastrointestinal (GI) symptoms include a positive response for any of the following individual symptoms: vomiting, diarrhea, stomachache or nausea. The individual symptoms in the respiratory category were sore throat, bad cough or a chest cold, and in the "other" category they were fever (greater than 100°F), headache for more than three hours, and backache. Disabling gastrointestinal symptoms (DGI) were defined as any one gastrointestinal symptom plus any one of the following characteristics: stayed home due to symptoms, stayed in bed due to symptoms or sought medical help due to symptoms. The highly credible gastrointestinal (HCGI) symptoms are combinations of unmistakably recognized individual symptoms used to establish the credibility of the gastrointestinal illness. These multiple symptom combinations were used because of the potential for variation in the interpretation of many characteristics used to describe symptomatic illness. HCGI symptoms are defined as any one of the following: (1) vomiting, (2) diarrhea with fever or a disabling condition (remained home, remained in bed or sought medical advice due to symptoms) and (3) stomachache or nausea accompanied by a fever.

In general, the symptom rates for swimmers were higher than those for nonswimmers, in all the categories. However, most of symptom rates, especially those unrelated to enteric illness, were not statistically significant ($p < 0.05$). This finding was similar to that observed in the early USPHS studies (4) conducted in the 1950's and in the marine recreational water studies conducted by the USEPA in the 1970's (6). Most of the statistically significant differences between swimmer and nonswimmer illness rates, with one exception, occurred in those symptomatic illness categories associated with enteric disease. Differences, which occurred in the "other" category, were usually due to fever with a temperature greater than 100°F. The significant swimming-associated illness rates also had a tendency to occur at the beach with the poorer quality water, Beach B. These data clearly show that there is a swimming-associated health effect and that the effect appears to be related to the microbiological quality of the bathing water. The illness rates by age showed a pattern similar to that observed in the marine bathing beach studies (6), wherein the highest rates for gastrointestinal illness occurred in children under 10 years old.

The geometric mean density and range of each of the indicators for each of the years is given in Table 4. The indicator densities were unexpectedly low at both beaches in 1979. In 1980, on the other hand, the indicator densities were high and on one or two occasions, extremely high as indicated by the range. The levels in 1982 were only moderately high relative to those observed in 1979. The bacterial indicator densities maintained their relative position at both beaches during the course of the study. The *E. coli* density was always highest and the enterococci densities were always lowest. Similarly, Beach B indicator densities were always greater than those observed at Beach A reflecting the nearness of the sewage treatment plant outfall.

Keystone Lake

The Keystone Lake studies were conducted in the summers of 1979 and 1980. The beaches were selected in a 1978 pilot study which showed that the water quality of these two sites was different based on bacterial indicator densities.

The demographic characteristics of the study participants are given elsewhere (42,43). The ratio of females to males was about equal in the swimmer category, but among nonswimmers about three-fifths of the participants were females. Similar ratios were observed in both 1979 and 1980. The socioeconomic status of swimmers and nonswimmers in each year of the study also was very similar. As in the Lake Erie study population, the age distribution of swimmers and nonswimmers was nearly constant from one year to the next. Individuals under the age of 20 years old comprised 45 to 50% of the swimmer population, whereas this age group made up 18

Table 3. Symptom Rates by Category for Swimmers and Nonswimmers at Lake Erie Beaches, 1979-1982 (from Reference 41)

Symptom Category	1979 Beach A S n=3020	1979 Beach A NS n=2349	1979 Beach B S n=2056	1979 Beach B NS n=2349	1980 Beach A S n=2907	1980 Beach A NS n=2944	1980 Beach B S n=2427	1980 Beach B NS n=2944	1982 Beach B S n=4374	1982 Beach B NS n=1650
Gastrointestinal	54.6[1]	44.7	56.4	44.7	55*	45.4	75.4*	45.4	58.3	46.7
Respiratory	50	42.6	55.4	42.6	36.8	53.4†	68.8	53.4	67.9	50.3
Other	30.1	25.5	40.4*	25.5	32	36.1	52.7	36.1	49.6	59.4
DGI[2]	12.3	10.2	18.5	10.2	8.9	8.3	16.9*	8.3	19.7	11.5
HCGI[3]	17.2	14.9	19.5	14.9	16.5	11.7	26.4*	11.7	24.9*	13.9

[1] Illness incidence rate per 1000.
[2] DGI - Disabling gastrointestinal symptoms.
[3] HCGI - Highly credible gastrointestinal symptoms.
*Swimmer illness rate significantly different from nonswimmer illness rate at $P < 0.05$ level.
†Nonswimmer illness rate significantly different from swimmer illness rate at $P < 0.05$ level.

Table 4. Bacterial Indicator Densities at Lake Erie, Pennsylvania Bathing Beaches, 1979, 1980, and 1982 (from Reference 41)

		Bacterial Indicator					
		Enterococci		*E. coli*		Fecal Coliforms	
Year	Beach	Mean	Range	Mean	Range	Mean	Range
1979	A	5[1]	1-29	23	7-268		
	B	13	2-49	47	16-413		
1980	A	25	3-101	137	66-536	37	1-191
	B	71	11-192	236	110-950	104	8-279
1982	B	20	4-87	146	23-524	60	27-107

[1]Geometric mean density per 100 mL.

to 20% of the nonswimmer population. In the nonswimmers, the largest age group was the 20 to 39 year old portion which ranged from 60 to 70%. The racial characteristics of the study populations in 1979 and 1980 were similar to each other and to that observed in the Lake Erie studies. About 96% of all swimmers and nonswimmers over the two years of the study were Caucasian.

The success rate for follow-up contacts are shown in Table 5. The overall success rate was about 85% with a range of 83 to 88%. Table 5 also shows the distribution of swimmers and nonswimmers in the total participating study population for the years 1979 and 1980. The percentage of nonswimmers in the total study population for each of the two beaches was 15% and 13% at the W beach and 15% and 11% at the E beach for the respective 1979 and 1980 swimming seasons. The pooling of nonswimming control groups within years increased the average percentage of nonswimmers in the total study population from an average of 13.7% to 24.2%.

The detailed health effects data for the Keystone Lake study trials are presented elsewhere (42,43). The symptom rates grouped by category are shown in Table 6. The symptoms which make up each category are the same as those defined previously for the Lake Erie studies. The trend toward higher symptomatic illness rates in

Table 5. Follow-up Success Rate for Beach Contacts at Keystone Lake, Oklahoma, 1979 and 1980

	1979		1980	
	Beach W	Beach E	Beach W	Beach E
Total contacts	4242*	3457	6616	4673
Follow-up interviews completed	3610	2859	5849	3981
No response or uncooperative	632	598	767	591
Success rate (%)	85	83	88	85
Total number of swimmers	3059	2440	5121	3562
Total number of nonswimmers	551	419	774	437

*Each contact one individual.

Table 6. Symptom Rates by Category for Swimmers and Nonswimmers at Keystone Lake Beaches, 1979 and 1980 (from References 42, 43)

Symptom Category	1979 Beach W S n=3059	1979 Beach W NS n=970	1979 Beach E S n=2440	1979 Beach E NS n=970	1980 Beach W S n=5121	1980 Beach W NS n=1211	1980 Beach E S n=3562	1980 Beach E NS n=1211
Gastrointestinal	61[1]	52	57	52	36.7*	19	37.9*	19
Respiratory	94	84	70	84	47*	32.2	51.1	32.2
Other	71*	53	55	53	29.3*	21.5	32*	21.5
DGI[2]	20.6	17.5	15.6	17.5	11.7	9.1	10.1	9.1
HCGI[3]	20.6	15.5	20	15.5	13.5	8.3	11.2	8.3

[1] Symptomatic illness rate per 1000 participants.
[2] DGI - Disabling gastrointestinal symptoms.
[3] HCGI - Highly credible gastrointestinal symptoms.
*Swimmers illness rate significantly different from nonswimmer illness rate at $P < 0.05$ level.

swimmers, relative to nonswimmers, observed in the Lake Erie studies also was evident in the Keystone Lake studies. The only exception to the trend occurred at Beach E in 1979 where the respiratory symptom rate in nonswimmers apparently was greater than that for swimmers although the difference was not statistically significant. In 1979 there was only one symptom category where the difference in illness rates between swimmers and nonswimmers was shown to be statistically different, and that occurred in the "other" category. Conversely, in 1980 statistically significant differences in illness rates between swimmers and nonswimmers were observed in three categories: GI, respiratory and "other" at Beach W, and in the GI and "other" categories at Beach E. The failure to find swimmer-nonswimmer differences in the highly credible GI category, in spite of the fact that statistically significant differences were found in the GI and "other" categories, was not unexpected since this was observed on a number of occasions in the marine studies (6).

The bacterial indicator densities observed during the 1979 swimming season were consistent between indicators (Table 7). Indicator densities at the beach nearest the source of the pollution were always higher than those at the more distant beach. The 1980 data, however, do not reflect such constancy. The enterococci and fecal coliform densities are not different between beaches as would be expected and the *E. coli* densities appear to be higher at the beach more distant from the pollution source. These inconsistent results may have been caused by heavy rains which occurred in the four days before the start of the beach study trials. In that short four-day period, 8.15 inches of rain was measured. This, in turn, caused the lake elevation to rise approximately nine feet above its normal level. The lake elevation did not return to its normal level until July 18, about a month after the heavy rains. The turbidity of the water also was increased during this time period. The effect these unusual events might have had on the swimmer illness rates is unknown.

Table 7. Indicator Densities at Keystone Lake Bathing Beaches, 1979-1980 (from References 42, 43)

		Enterococci		*E. coli*		Fecal Coliform	
Year	Beach	Mean[1]	Range	Mean	Range	Mean	Range
1979	W	38.8[2]	17-180	138	30-300	436	200-920
	E	6.8	2-98	19	1-44	51	NG[3]
1980	W	23	6-64	52	14-200	230	58-1300
	E	20	2-76	71	12-215	234	47-1600

[1]Geometric mean.
[2]Density per 100 ml.
[3]Not given.

SECTION 5

DEVELOPMENT OF A CRITERION

The development of a criterion which relates swimming-associated health effects to some measure of water quality requires that certain basic information must be available before a valid model can be established. One of the critical elements in such a model is to show that there is a significant excess of illness in bathers who swim in surface waters contaminated with domestic wastewater. The USPHS studies on the Ohio River and at other locations were an attempt to reach this objective (4).

Those studies did show that there was a barely detectable health effect when the bathing water contained about 2,300 coliforms per 100 ml, an indication that the water was contaminated with fecal material from humans or warm-blooded animals. The effect was shown only for symptomatic gastrointestinal illness and not for the respiratory or "other" categories of symptoms.

The more recent EPA marine bathing beach studies also showed, in unquestionable terms, that one of the main health effects related to swimming in sewage-polluted water was gastrointestinal illness (6). Although increased rates of respiratory and "other" symptomatic illness were related to swimming activity alone, only the rate of gastrointestinal illness increased significantly as the quality of the bathing water decreased. The EPA marine studies also accomplished what the early USPHS studies could not accomplish, that is, show that there is a risk of enteric illness due to swimming in polluted marine waters.

The studies described in this report clearly confirm that the risk of contracting gastrointestinal illness greatly increases if a person swims in water contaminated with human domestic wastes. The Lake Erie bathing beach trials showed that almost all of the statistically significant differences in swimming-associated illness rates occurred only in those symptom categories related to gastroenteric illness and that there was a greater preponderance of significant differences at those beaches having the highest degree of fecal contamination. The results of the Keystone Lake study were not as clear-cut as those at the Lake Erie beaches, but the observed statistically significant swimming-associated illness rates were related mainly to gastrointestinal symptomatology and "other" symptoms such as fever greater than 100°F. Two single exceptions to these findings were the swimmer-nonswimmer rate differences in the respiratory category which occurred at Lake Erie and Keystone Lake beaches in 1980.

The second objective of this report was to determine which indicator of fecal contamination, enterococci, *E. coli* or fecal coliforms showed the strongest relationship to swimming-associated illness. Enterococci and *E. coli* were considered because they showed the "best" relationship to swimming-associated illness in the marine recreational water quality studies. Enterococci were judged to be superior to *E. coli* for use in marine waters (44). Fecal coliforms also were examined in the freshwater studies because they are the currently recommended indicator group for monitoring recreational water quality.

Three statistics related to regression and correlation analysis were used to determine which bacterial indicator had the strongest relationship to swimming-associated illness in freshwater environments. They are the slope of the regression equation, the standard error of the estimate and the correlation coefficient. In the marine bathing beach studies, only the correlation coefficient was used to compare the "strength of association" of various indicator bacteria to swimming-associated illness. Since the number of paired data points available in the freshwater studies is small, it seemed appropriate to use ancillary descriptive information to arrive at a

judgment as to which indicator should be used to establish the relationship between water quality and swimming-associated health effects. The slope was chosen because it indicates how large a change in a health effect will be associated with a change in water quality. It also has the advantage of being amenable to statistical testing to determine if it is different from zero or some other slope. The standard error of the estimate is useful because it is an average measure of the vertical distances of the observed points from the regression line. It is defined as the square root of the sum of the squared vertical distances from the regression line divided by the number of points. Thus, the smaller this value, the closer the points are to the regression line. The correlation coefficient is included so that the results of the freshwater data can be directly compared to the marine data. Since the correlation coefficient can be affected by the magnitude of the slope and the standard error of the estimate, but gives no indication of the relative influence of these two components, less weight will be attached to this statistic relative to the other two.

Table 9 is a summary of the statistics used to describe the relationship of gastrointestinal illness to enterococci, *E. coli* and fecal coliforms. The statistics were generated using the summary data given in Table 8. The first conclusion that can be drawn from the data in this table is that fecal coliform densities in freshwater are unrelated to swimming-associated gastroenteritis. The slope of the regression lines of highly credible and total GI symptomatic illness on fecal coliform densities were not significantly different from zero. This finding was very similar to that reported for the relationship of HCGI and total GI symptoms to fecal coliform densities in studies at marine bathing beaches (6). In those studies, correlation coefficients for HCGI and total GI symptoms on fecal coliform densities for data analyzed by summer and by beach were respectively—0.01 and 0.01. The implication of these results is quite clear. Bacteria from sources other than the gastrointestinal tract of man and other warm-blooded animals, which fit the definition of fecal coliform given in Standard Methods for the Examination of Water and Wastewater (38), are present at densities high enough to sufficiently eliminate the usefulness of fecal coliforms as an indicator

Table 8. Summary of Microbiological and Epidemiological Results from Lake Erie and Keystone Lake Bathing Beach Studies

			Geometric Mean		Indicator Density[1]	Symptom Rate	
Location	Year	Beach	Entero-cocci	*E. coli*	Fecal Coliforms	Total GI	HCGI
Erie	1979	A	5.2[2]	23	N.D.	9.9[3]	2.3
		B	13	47	N.D.	11.7	4.6
Erie	1980	A	25	137	37	9.6*	4.8
		B	71	236	104	30.0*	14.7*
Erie	1982	B	20	146	60	11.6	11*
Keystone	1979	E	38.8	138	436	9.0	5.1
		W	6.8	19	51	5.0	0.5
Keystone	1980	E	23	52	230	17.7*	5.2
		W	20	71	234	18.9*	3.0

[1]Obtained from trials grouped by beach and year.
[2]Indicator density per 100 mL.
[3]Swimmer, nonswimmer illness rate difference per 1000 individuals.
*Swimmers illness rate significantly different from nonswimmer illness rate at $P < 0.05$ level.

of fecal contamination of surface waters. This hypothesis is supported by the numerous reports that at least one genus within the fecal coliform group can readily grow to high densities in the presence of industrial wastewaters. *Klebsiella pneumonia* and other *Klebsiella* species grow to extremely high densities in pulp mill wastes (45,46), textile processing plant wastes (47) and cotton mill wastes (48). Industrial wastes are not the only source of thermotolerant *Klebsiella*. The proportion of *Klebsiella* in fecal coliform populations observed in secondary effluent samples from seven sewage treatment plants has been found to range from 13 to 42% (unpublished data). Furthermore, this genus was shown by Kinney, Drummond and Hanes (49) to be much more resistant to chlorine than other genera of the fecal coliform group. This latter observation might account for the finding that more than one-half of 24 water samples collected over a 15-day period from Beach B on Lake Erie had fecal coliform populations that were more than 30% thermotolerant *Klebsiella*. The percentage of *Klebsiella* ranged from 17 to 73% of the fecal coliforms. This ubiquitous organism, many strains of which fit the fecal coliform definition, may very well be a partial reason why fecal coliform densities do not show a direct relationship to swimming-associated GI illness.

Escherichia coli densities on the other hand show an excellent relationship to swimming-associated GI illness. Since *E. coli* is by definition a fecal coliform, this strong association to GI illness can only be attributed to the use of a highly selective/differential enumeration method which effectively eliminates potential interfering organisms. The slopes of regression lines calculated using illness rates from the HCGI and total GI categories against *E. coli* densities both showed a statistically significant change in illness rates with changes in indicator densities. The standard error of the estimate associated with HCGI symptom rates was the smallest of all the estimates, indicating that this indicator had the closest fit of points to the regression equation. The correlation coefficient for the association between HCGI symptoms and *E. coli* densities was 0.804, the largest of all the correlation coefficients and indicating that *E. coli* shows the "best" relationship to swimming-associated GI illness. This rationale, which was used in the marine recreational water quality studies to choose the "best" indicator, may not be applicable to the freshwater studies. This is suggested because of the equally excellent relationship between GI illness rates and enterococci densities. The slopes for the two symptom categories generated using enterococci as the independent variable are very similar to those obtained using *E. coli*.

If a statistical significance test is performed to test the hypothesis that the slope of the regression line of HCGI illness rates on enterococci densities equals the slope of the regression line of HCGI illness rates on *E. coli* densities, it can be shown that the

Table 9. Summary of Regression Statistics Related to Swimming-Associated Illness and Water Quality Indicators

Indicator	Symptom Category	Slope	Y Intercept	Std. Error of Estimate	Correlation Coefficient	Departure from Linearity
Enterococci	Total GI	14.30*	-4.50	5.21	.673	NS[1]
	HCGI	9.40	-6.28	2.97	.744	NS
E. coli	Total GI	10.39*	-5.56	5.97	.528	NS
	HCGI	9.40*	-11.74	2.49	.804	NS
Fecal Coliform	Total GI	5.21	3.81	7.53	.249	NS
	HCGI	-0.98	8.35	4.49	-.081	NS

[1]NS - No significant departure from linearity.
*Slope of regression line is significantly different from zero.

slopes are not significantly different ($p > 0.05$). Furthermore, it cannot be shown that the y-intercepts or the correlation coefficients associated with these two indicators are significantly different ($p > 0.05$). Since the two indicators show equally strong associations to swimming-associated gastrointestinal illness, it seems that an appropriate approach would be to present two criteria and recommend one of the two based on factors unrelated to the statistics of regression and correlation analysis.

Criteria for Freshwater Bathing Areas

Cabelli (6) has defined a water quality criterion developed for use with indicator systems as "a quantifiable relationship between the density of the indicator in the water and the potential human health risks involved in the water's use." The health effects-water quality criterion that will be developed in this section fits the above definition, and its purpose will be to provide a quantifiable relationship which can be used to set water quality guidelines or standards for fresh bathing waters. The regression lines which characterize the relationship between highly credible and total gastrointestinal symptom rates, and bacterial indicator densities were developed from the regression coefficients given in Table 9. It was assumed that the logarithm of the bacterial density would graph linearly against the incidence of disease since this model had previously been shown to be applicable to similar data in the marine bathing beach studies (6). The validity of the linear relationship was examined using the run test (50), a crude but simple method for determining departures from linearity. None of the estimated lines showed statistically significant departures from linearity ($p > 0.05$). The regression lines for highly credible and total gastrointestinal symptom rates on indicator densities are shown for *E. coli*, enterococci and fecal coliforms in Figures 1, 2 and 3. Each point represents a pair of variables, the geometric mean indicator density obtained from water samples collected at a beach over a single bathing season and the corresponding swimming-associated illness rate. The gastrointestinal illness rate and fecal coliform density data displayed in Figure 3 serve to emphasize the lack of association between these two variables. This lack of association was indicated in Table 9 by the low value of the correlation coefficient and the flatness of the slope. The regression lines for *E. coli* and enterococci, on the other hand, show significant changes in the symptomatic illness rates with changes in indicator densities. Furthermore, all of the observed data points are in close proximity to the estimated regression lines, especially those for the highly credible symptoms. The regression lines for *E. coli* and enterococci are remarkably similar with respect to slope, standard error of the estimate and correlation coefficient. The only differences of any significance are the higher densities of *E. coli* relative to enterococci as manifested by the greater y-intercepts associated with the *E. coli* regression lines, especially in the case of the HCGI symptoms. The average highly credible GI symptom rates were about 43% of the average rates observed for total GI symptoms. The overall mean enterococci density for the nine trials was 18.9 per 100 ml, while that for *E. coli* was 71.9 per 100 ml. These results were not unexpected, since enterococci are typically found at densities lower than *E. coli*, both in human feces (51) and in sewage effluents (52).

The strength of the relationship between health effects and the various water quality indicators examined in the marine recreational water quality study showed clear-cut differences and, therefore, the choice of the "best" indicator was obvious. The selection of the "best" indicator with respect to the strength of the relationship between water quality indicator and swimming-associated illness is not obvious in the results of the freshwater studies. The similarity of the data describing the relationship of swimming-associated illness to *E. coli* and enterococci densities is so great that a criterion will be presented for each bacterial indicator. The health effects-water quality criteria for *E. coli* and enterococci are shown in Figures 4 and 5. Each figure shows the estimated lines of best fit and the 95% confidence limits of the lines.

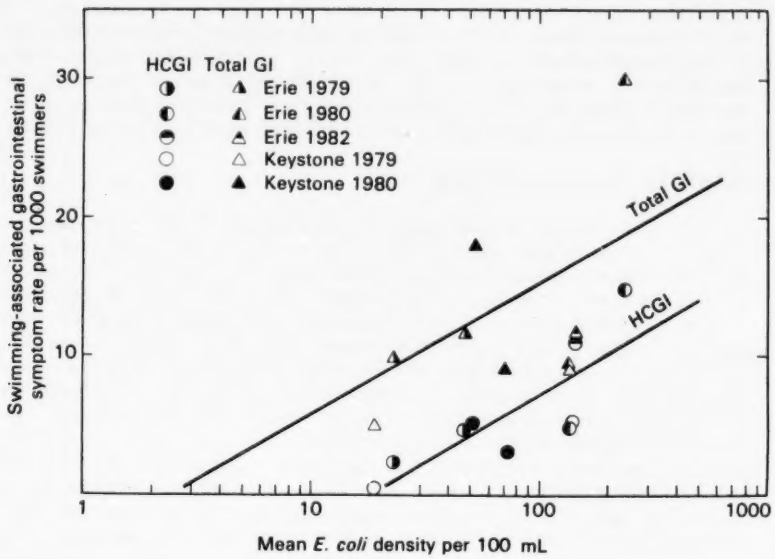

Figure 1. Estimated regression lines for highly credible and total gastrointestinal symptom rates on *E. coli* densities.

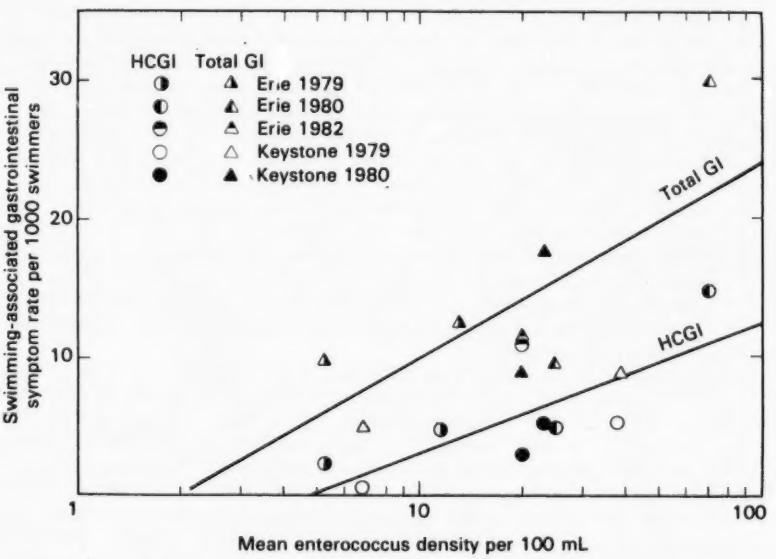

Figure 2. Estimated regression lines for highly credible and total gastrointestinal symptom rates on enterococci densities.

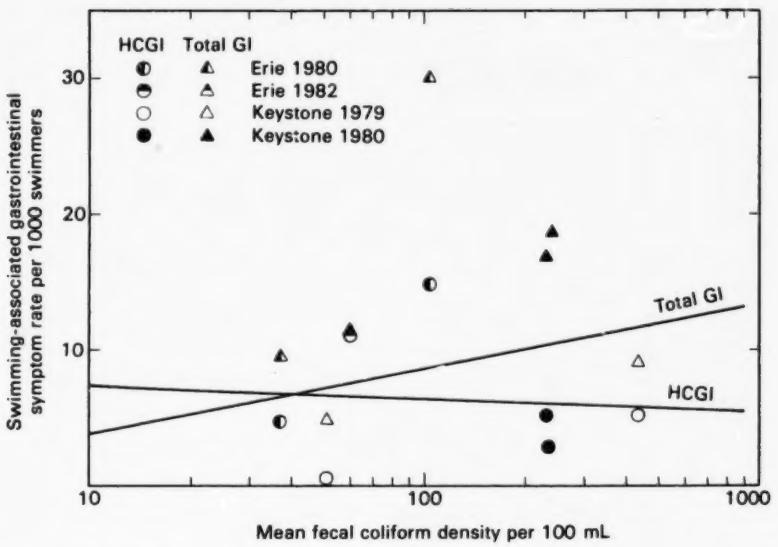

Figure 3. Estimated regression lines for highly credible and total gastrointestinal symptom rates on fecal coliform densities.

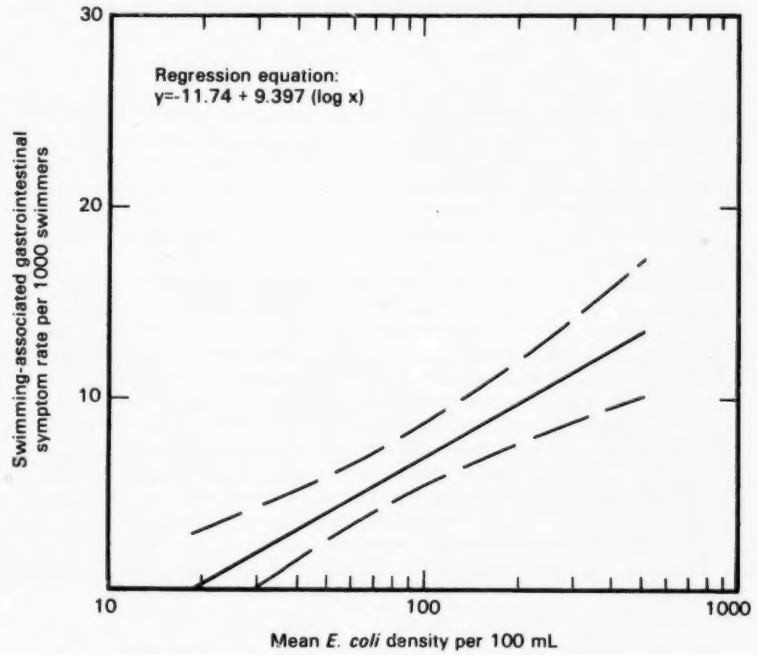

Figure 4. Criterion for estimating swimming-associated gastrointestinal illness rate from the geometric mean density of *E. coli* per 100 mL in freshwater samples.

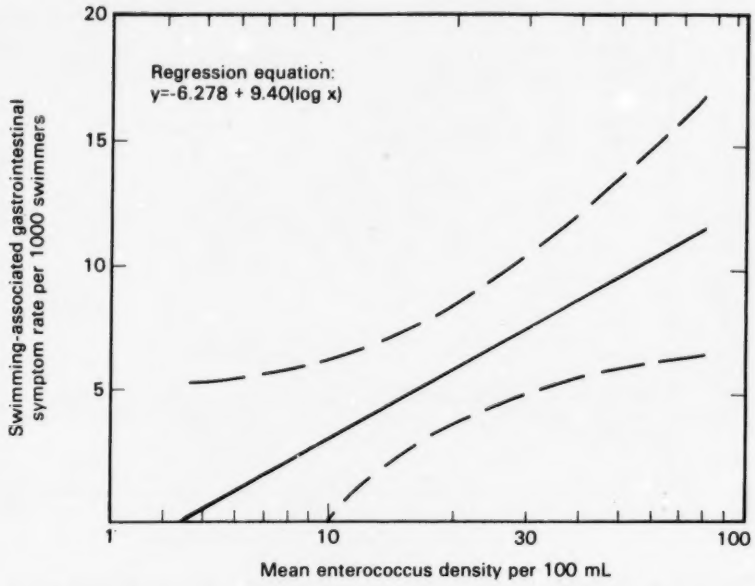

Figure 5. Criterion for estimating swimming-associated gastrointestinal illness rate from geometric mean density of enterococci per 100 mL in freshwater samples.

Although data for both highly credible and total GI symptomatic illness have been shown, only the former will be used to develop criteria for fresh recreational bathing waters. The reason for not considering a criterion using total GI symptomatology is two-fold. First, the regression and correlation analyses indicate that the strength of the relationship between the indicators and highly credible symptom rates is much greater than that with total GI symptom rates, and second, as pointed out by Cabelli (6), highly credible symptoms should be used "because of the greater credibility of its data base and because it is more conducive to economic analysis."

The two figures shown are useful for approximately determining the number of swimming-associated gastrointestinal illnesses that might be expected at a bathing beach where the density of *E. coli* or enterococci falls within the range of the criterion. However, a relationship of this type most likely will be used to determine, not what the risk is but what the water quality should be after an acceptable risk level has been agreed upon by a local or state authority. Since the two characteristics (indicator density and illness rate) used to develop the criterion both show variability and only the variability of the dependent characteristic is accounted for in the regression equation and its 95% confidence limits, it is necessary to show a second relationship where the indicator densities play the role of the dependent characteristic. The regression line for *E. coli* on swimming-associated illness, the equation of the line and the 95% confidence limits of the line are shown in Figure 6. A similar equation, line and limits for enterococci are shown in Figure 7. Either one of the relationships shown in Figures 6 and 7 can be used to establish guidelines or standards based on acceptable risk.

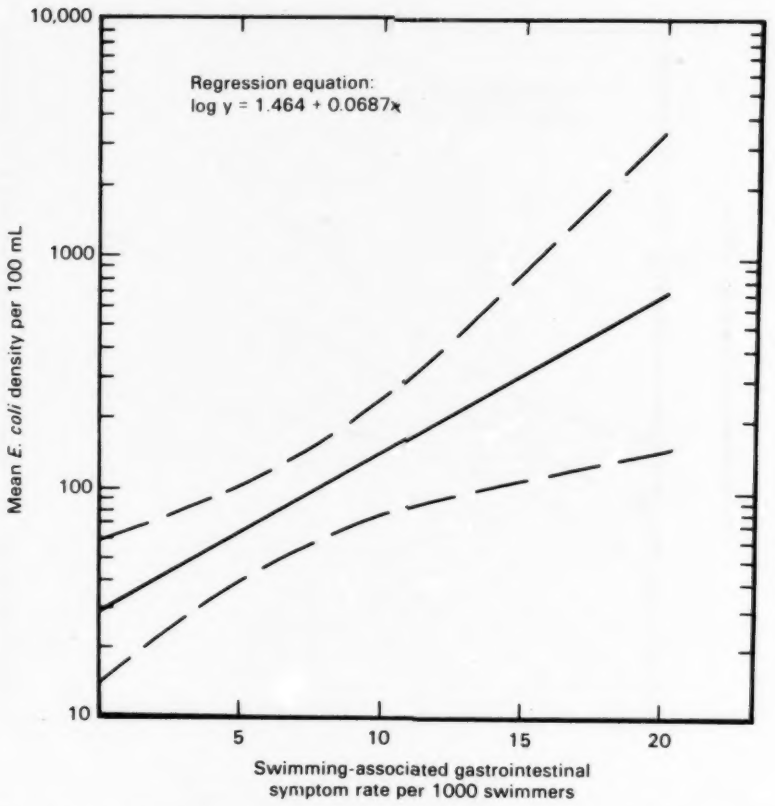

Figure 6. Criterion for estimating the geometric mean *E. coli* density per 100 mL from an acceptable risk level of swimming-associated gastrointestinal illness.

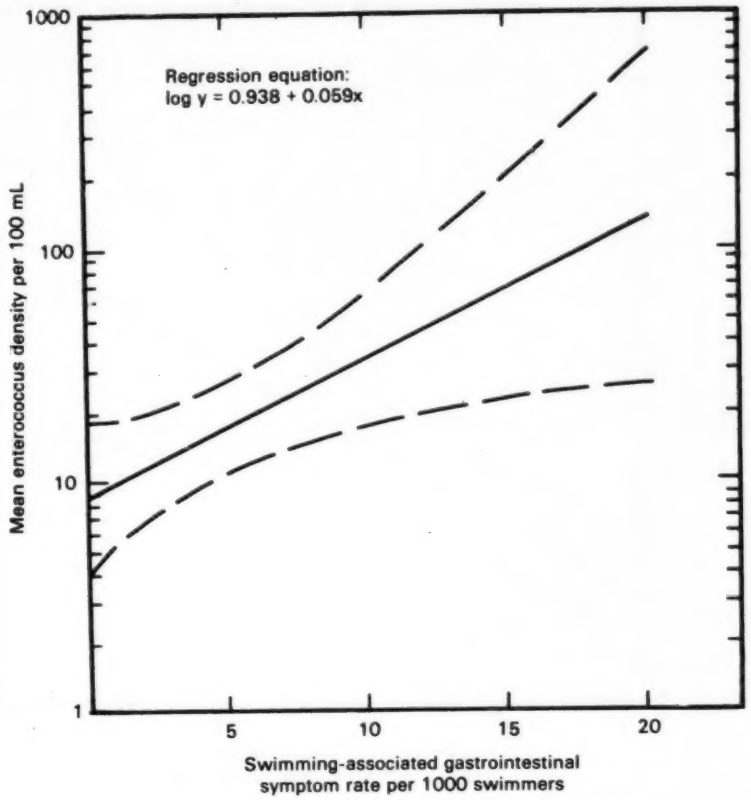

Figure 7. Criterion for estimating the geometric mean enterococci density per 100 mL from an acceptable risk level of swimming-associated gastrointestinal illness.

SECTION 6

MARINE VERSUS FRESHWATER CRITERIA

The recreational water quality studies carried out by the USPHS in the early 1950's (4) could not detect a swimming-associated illness effect at two marine bathing beaches on Long Island, New York. Since swimming-associated gastrointestinal health effects were observed at a freshwater bathing site in the same study series, it was assumed that the results of the EPA fresh recreational water quality studies would reveal higher swimming-associated gastrointestinal illness rates than were found in the EPA marine bathing beach studies. This assumption posed a further question as to whether or not a single criterion could be used for both fresh and marine bathing beach waters. When the results of the freshwater studies were compared to those of the marine studies (Figure 8), it was clear that the illness rates in bathers swimming at marine bathing beaches were significantly higher ($p < 0.05$) than those in freshwater swimmers when the data were analyzed using the Wilcoxon rank sum test (53). The mean of the marine highly credible G.I. illness rate data (15.2 per 1000), grouped by beach and year, was 2.67 times greater than the mean for the highly credible G.I. illness rates in freshwater swimmers (5.7 per 1000). The Wilcoxon rank sum test (53) also was used to show that the means for the *E. coli* and enterococci indicator densities in marine waters were not significantly different from the means of those two indicators in fresh waters (Figure 8). The similarity in indicator densities in freshwater and seawater can be explained on the basis of the limitations placed on the selection of study sites and the difference in gastrointestinal illness rates between marine and freshwater swimmers can possibly be accounted for by the die-off rates of indicator bacteria and pathogens in marine and freshwaters.

The constraints of the site selection process stipulated that the water quality at each location had to meet local standards. All of the sites where studies were conducted used the 200 fecal coliform per 100 ml standard and since the bathing waters were usually in compliance with the standard, it is not surprising that there is some uniformity of indicator densities in the marine and fresh beach waters.

The survival of coliforms in seawater and freshwater was examined by Chamberlin and Mitchell (54). They analyzed 87 seawater studies and 28 freshwater studies on indicator bacteria die-off. The results of their analysis indicated that the median T_{90} value, i.e., the time it takes for 90% of the indicator bacteria to die-off, from the seawater studies was 2.2 hours, whereas the mean T_{90} value from the freshwater studies was 57.6 hours. Hanes and Fragala (55) have shown that under laboratory conditions enterococci and *E. coli* behave much like coliforms do under field conditions. *E. coli* had a T_{90} of 18 hours in seawater and 110 hours in freshwater, while enterococci had a T_{90} of 47 hours in seawater and 71 hours in freshwater. The differential die-off of indicators by itself, however, is not sufficient to explain the difference in gastrointestinal illness rates between marine and freshwater swimmers. The linear relationships between gastroenteritis and *E. coli* or enterococci in marine and fresh recreational waters shown in Figures 9 and 10 provide additional information which might be useful for answering the question. The coefficients used to generate the regression lines in Figures 9 and 10 are given in Table 10. It is noteworthy, that with the exception of the regression line showing the relationship between swimming-associated illness in marine waters and *E. coli* densities, all of the estimated lines in Figures 9 and 10 intersect the indicator density axis at mean indicator densities greater than 1 per 100 ml. This suggests that the infectious dose level of the etiologic agent disappears before the mean indicator densities become

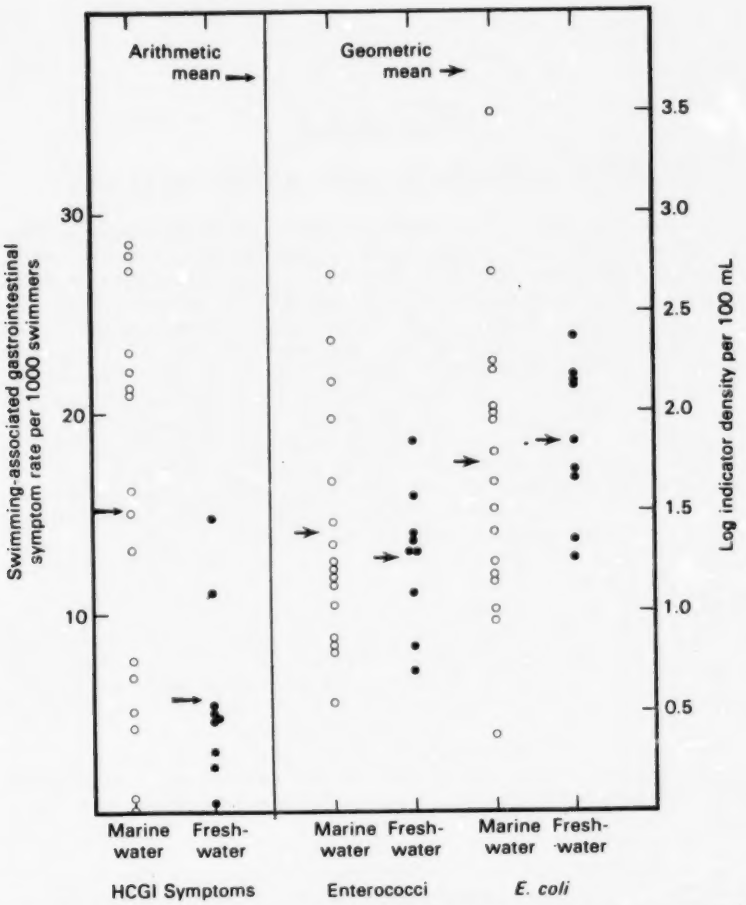

Figure 8. Data summary of highly credible gastrointestinal symptom rates and indicator densities from marine and freshwater studies. (Marine data obtained from Tables 7 and 8, Reference 6.)

unmeasurable in both marine and freshwater environments. The implication of this observation is that the etiologic agent, which is assumed to be a virus (56), probably dies off at the same rate, whether in seawater or freshwater, since the swimming-associated effect of the pathogen infectious dose approaches zero as the indicator density approaches a value of 1 per 100 ml. This would not be an unreasonable assumption, since Cioglio and Loddo (57) have shown that strains of Polio, ECHO$_6$ and Coxsackie virus had similar die-off rates in river and seawater held at 25°C. Although it is unlikely that these viruses are the cause of swimming-associated gastroenteritis, it is possible that the unidentified etiologic agent behaves in a similar fashion. The assumed similar die-off rate of the pathogen in freshwater and seawater, coupled with the greater die-off of indicator bacteria in seawater than in freshwater, could account for the difference in gastroenteritis rates between marine and freshwater swimmers, especially when both types of recreational waters are required to meet the same microbial standard. Thus, an indicator would decay rapidly in

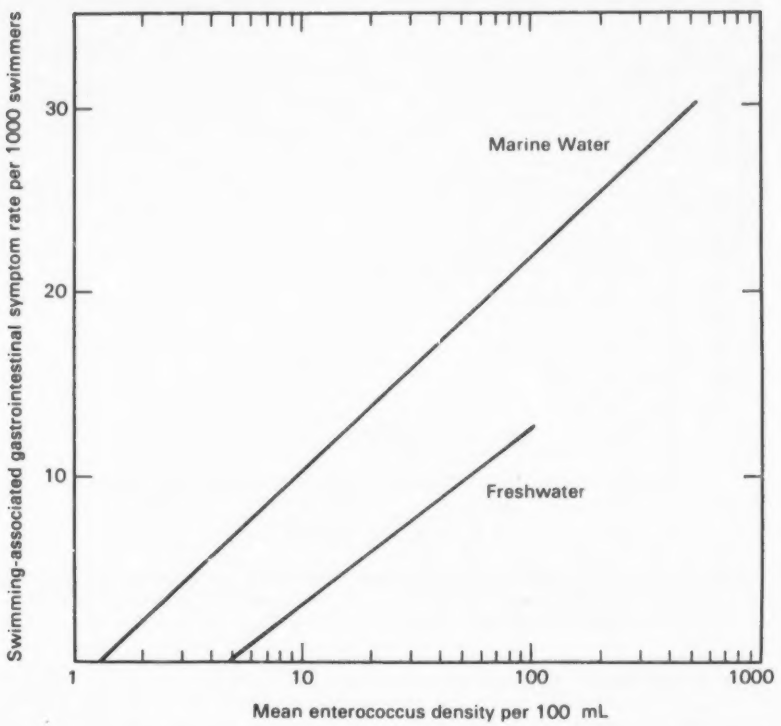

Figure 9. Marine and freshwater criteria for swimming-associated gastrointestinal illness and water quality using enterococci to measure the water quality. (Marine data obtained from Table 7, Reference 6.)

Table 10. Summary of Statistics Related to Marine and Freshwater Criteria for Highly Credible Swimming-Associated Illness and Water Quality Indicators, *E. coli* and Enterococci

Type of Water	Mean Swimming-Associated Illness Rate	Geometric Mean Density		Slope		Standard Error Est.		Correlation Coefficient	
		EC[1]	ENT[2]	EC	ENT	EC	ENT	EC	ENT
Marine[3]	15.2	56	25	7.3	11.6	8.5	6.7	.512	.712
Fresh	5.7	72	20	9.4	9.4	2.5	2.8	.804	.744

[1]EC - *E. coli.*
[2]ENT - enterococci
[3]Illness rates and bacterial indicator density data obtained from Reference 6.

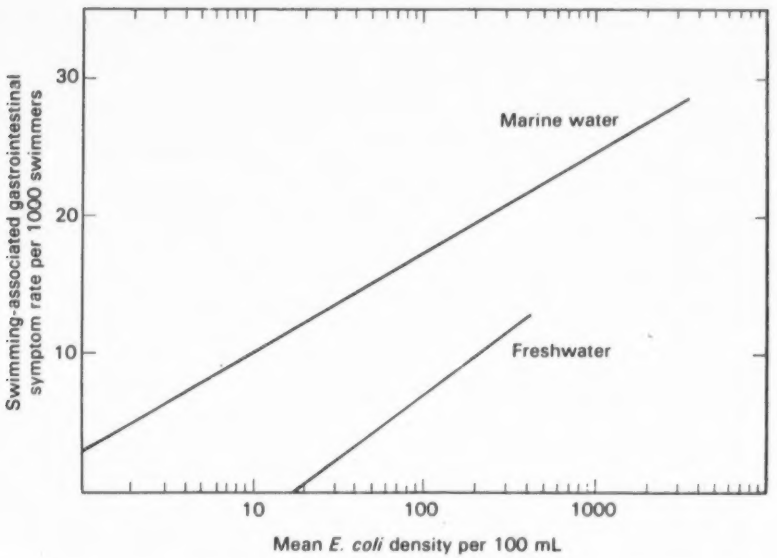

Figure 10. Marine and freshwater criteria for swimming-associated gastrointestinal illness and water quality using *E. coli* to measure the water quality. (Marine data obtained from Table 9, Reference 6.)

seawater while the pathogen does not, leaving an excess of pathogen once the standard is reached. In freshwater, the indicator decays at the same rate or slower than the pathogen, which results in a low density of pathogen by the time the standard is attained. At equivalent indicator densities, there will be an excess of pathogen in marine waters relative to what would be found in freshwaters, and therefore a higher illness rate will be observed in marine waters. Thus, the difference in marine and freshwater swimmer illness rates is not only statistically significant, but also is apparently compatible with many of the known characteristics of indicators and pathogens associated with the observed phenomenon. The significance of these findings is that a single water quality criterion for seawater and freshwater has been effectively eliminated from consideration, and therefore a separate criterion should be used for each type of bathing water.

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